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Phase Perturbation Measurements through a Heated Ionosphere

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Abstract

HF-radiowaves incident on an overdense (i.e., HF-frequency < penetration frequency) ionosphere are known to produce electron density irregularities. The purpose of this investigation was to determine the effect of such ionospheric irregularities on the phase of UHF-radiowaves. For that purpose the phase of radiowaves originating from celestial radio sources was observed with two antennas. The radiosources were chosen such that the line of sight to at least one of the antennas (usually both) passed through the modified volume of the ionosphere. Observations at 430 MHz and at 2380 MHz indicated that natural irregularities have a much stronger effect on the UHF phase fluctuations than the HF-induced irregularities for presently achieved HF-power densities of 20-80 $\mu W/m^2$. It is not clear whether some of the effects observed are the result of HF-modification of the ionosphere. Upper limits on the phase perturbations produced by HF-modification are 10° at 2380 MHz and 80° at 430 MHz.

1. Introduction

Modification of the ionosphere by HF radiowaves produces electron density irregularities of various scale sizes. It is of increasing interest what effects a microwave beam has on the ionosphere. A study in connection with the proposed Solar Power Satellite (SPS) has been conducted a few years ago [Duncan and Gordon, 1977]. In a later report [Gordon and Duncan, 1978] increased concern was expressed on the effects of ionospheric electron density irregularities on the uplink pilot beam. That ionospheric electron density irregularities which are the result of overdense HF-modification produce intensity fluctuations of radio stars, which have a line of sight through the perturbed volume, was shown by several workers. That HF induced effects are observable at frequencies as high as 430 MHz and 1400 MHz was shown recently by [Frey, 1982], where it was also discussed how filtering-effects reduce the measured intensity fluctuations of radio sources at UHF. Since the purpose of the uplink pilot beam is to return phase information to the SPS an experiment was performed to measure phase distortions on the wavefronts as they pass through an HF-modified ionosphere. This was done by observing radio sources with two antennas (the Arecibo 300m-dish and the Los Caños 30m-dish) separated by 10.7 km and cross-correlating the measured electric field vector to obtain the relative phase delay. Observations were performed at 430 MHz and at 2380 MHz, the latter being almost the same frequency as is planned for the SPS-microwave beam.

2. Experimental Procedure

The relative phase perturbations were deduced by shifting the experimentally observed interference fringes with respect to the theoretically expected interference fringes. The observed interference fringes were obtained as the cross correlation between the electric field vectors measured at two different antennas. The interference fringes consist of an averaged data point every 25 msec. 40 of those data points are used to fit the fringes every second. The experimental arrangement is shown in Figs. 1 and 2. In Fig. 1 the location of the two antennas used for the phase measurements is shown with the Los Caños 30m-dish being at a separation of 10.7 km from the Arecibo 300m-dish. Also shown is the location of the HF-facility. Shown in Fig. 2 is the projection of the 3-dimensional geometry onto the meridian plane on which the HF-facility is located. The HF-beam and the HF modified volume are shown for an assumed interaction height of ~ 300 km and for an HF-frequency of 5.1 MHz (neglecting refraction). Also shown are the lines of sight from the two antennas to a given radiosource (3C47 & CTA21) used for the phase measurement. The radiosource 3C47 has a declination of 20.7° and radiosource CTA21 has a declination of 16.3°. The other two sources used are B0149+21 with a declination of 21.9° and 3C43.0 with a declination of 23.4°. It takes 15-20 minutes for the line of sight to a suitable radiosource to scan across the HF-beam at a height of ~ 300 km. All observations were performed at nighttime to reduce D-region absorption of the HF-wave and to reduce interplanetary scintillation effects.

It was observed in the past [Frey, 1982] that the response time for the irregularities to develop is 2-3 minutes after the HF-power is turned on. The same observations also indicated that the life time of the irregularities produced can be on the order of hours. For these reasons the observation scheme

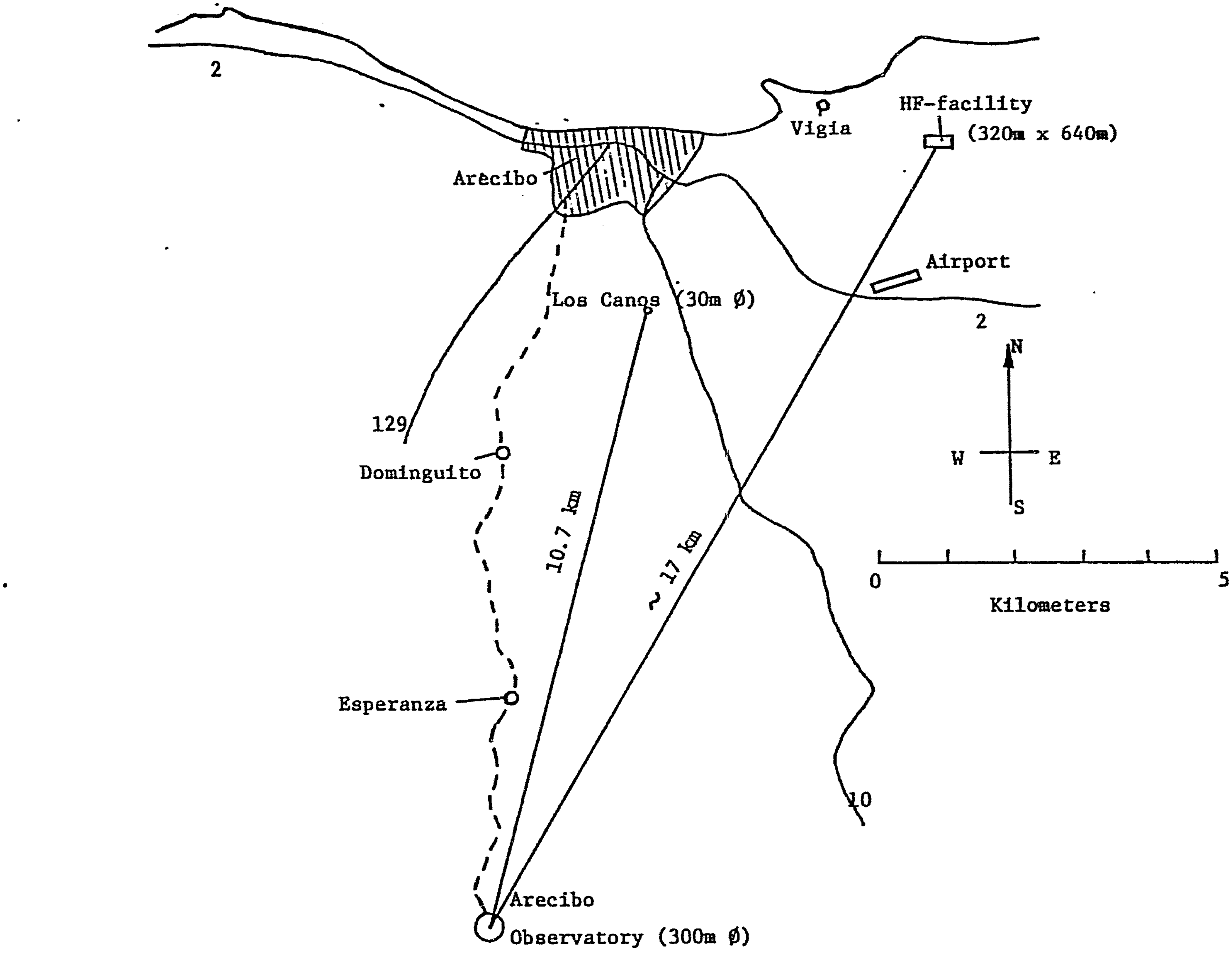

2
HF-facility
(320m x 640m)
Vigia
Arecibo
Airport
Los Canos (30m ∅)
2
N
129
W
E
Dominguito
S
10.7 km
~ 17 km
0
5
Kilometers
Esperanza
10
Arecibo
Observatory (300m ∅)

Figure 1

PROJECTION OF OBSERVING GEOMETRY INTO THE MERIDIAN PLANE PASSING THROUGH THE HF-FACILITY

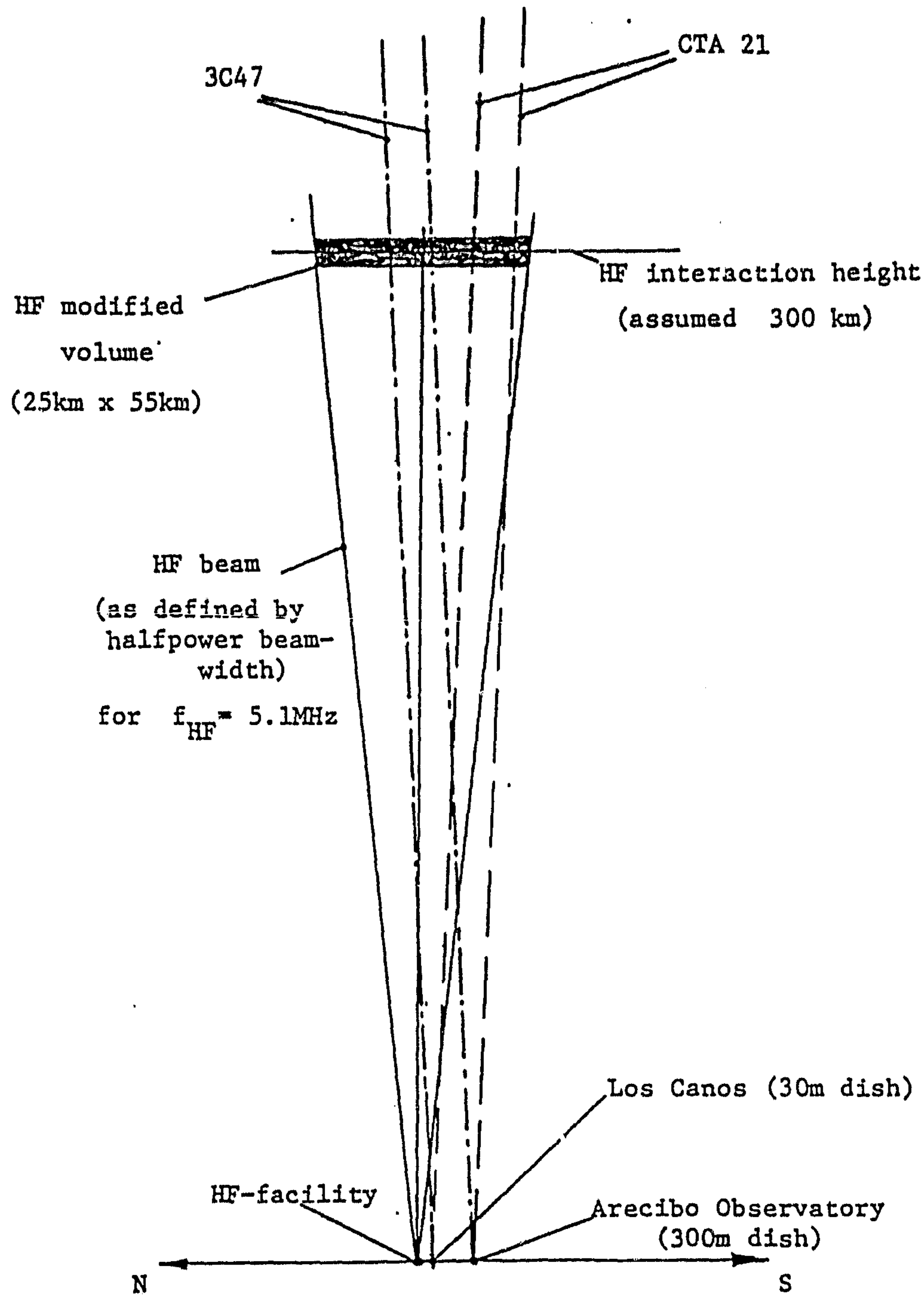


Figure 2

for the measurements reported here was the following: (a) A source was observed for 10-20 min. before the line of sight entered the modified volume while the HF-power had been off for an extended period (usually more than one hour). (b) As the line of sight to the radiosource was well within the HF-beam (as defined by the halfpower beamwidth) the HF-power was turned on, in an attempt to see an increase in ionospheric electron density irregularities.

The frequencies used for the HF-modification were 5.08 MHz and 7.3 MHz. The maximum HF-power densities and the equivalent maximum SPS power densities for the individual observations are shown in Table 1. As will be discussed in section 4, the observed effects during overdense heating were too small to be related with reasonable certainty to the HF-power.

Since past experiments [Frey, 1982] have shown that irregularities due to underdense HF-heating are much weaker (if they exist) than irregularities due to overdense heating, all experimental effort (telescope time and HF-time) was used to study the effects of overdense HF-heating.

3. Observations

Useful measurements were recorded on tape on the 16/17 Sept. 81 (2380 MHz) and on the 12/13 Oct. 81 (430 MHz). A summary of the observations is presented in Table 1. In section a) the 2380 MHz observations will be presented and the 430 MHz observations are shown in section b).

a) 2380 MHz--Observations

On the 16 Sept. 81 radio source 3C43.0 was observed between 1:37:20 AST and 1:47:59 AST without HF-heating. The raw data are shown in Fig. 4.1.a) and the detrended data are shown on an expanded scale in Fig. 4.2.a). Natural irregularities are observed which produce phase fluctuations of ~ 50° over time periods of 80 seconds or longer. In addition, pulses of ~ 8° phase deviation occur with an interpulse period of ~ 36 sec (indicated by arrows in Fig. 4.2.a). These are believed to be artifacts of the instrumentation.

During the period starting at 2:11:50 AST and ending at 3:00:39 AST the radio source B0149+21 was observed. Natural irregularities still produce phase fluctuations of ~ 50° over time periods of 80 seconds or more. Occasionally phase fluctuations are rapid enough (see Figs. 4.2.b & e) to vary the phase at a rate of 1-2°/sec. At 2:26:46 AST about 4 minutes before the line of sight to the radio source passed near the center of the HF-beam, all four HF-transmitters were turned on and fed 100 kW each into the full HF antenna-array. At an HF-frequency of 5.08 MHz this corresponds to a power density of ~ 56 $\mu W/m^2$. The SPS-equivalent (2450 MHz) power density is 1.3 mW/cm^2. assuming ohmic heating which is inversely proportional to the frequency squared. No effects of HF-modification on the observed phase fluctuations are apparent in Figures 4.1 and 4.2. At 2:35 AST the HF-power was turned off. Starting at 3:16:30 AST the radio source CTA21 was observed until 4:42:29 AST.

Table 1: Summary of Observations

2380 MHz--Observations

date	observing-time	radio source	comments	max. Hf-power density	SPS equiv. power density (2450 MHz)	Refer to Figures
16 Sept. 81	1:37:20 to 1:47:59	3C43.0	no heating			4.1 & 4.2
	2:11:50 to 3:00:39	B0149+21	f_{HF} = 5.08 MHz	56 μW/m^2	1.3 mW/cm^2	4.1 & 4.2
	3:16:30 to 4:53:29	CTA21	f_{HF} = 5.08 MHz	84 μW/m^2	1.9 mW/cm^2	5.1 & 5.2
17 Sept. 81	2:11:20 to 2:57:49	B0149+21	f_{HF} = 7.3 MHz	44 μW/m^2	0.5 mW/cm^2	6.1 & 6.2
	3:10:40 to 4:46:19	CTA21	f_{HF} = 7.3 MHz	66 μW/m^2	0.7 mW/cm^2	7.1 & 7.2

430 MHz--Observations

date	observing-time	radio source	comments	max. HF-power density	SPS equiv. power density (2450 MHz)	Refer to Figures
12 Oct. 81	1:06:38 to 1:28:37	3C47	effect of HF unknown			8.1 & 8.2
	2:05:08 to 2:26:47	CTA21	f_{HF} = 5.08 MHz	42 μW/m^2	1.0 mW/cm^2	9.1 & 9.2
13 Oct. 81	0:07:48 to 0:51:47	3C47	f_{HF} = 7.3 MHz	22 μW/m^2	0.25 mW/cm^2	10.1 & 10.2

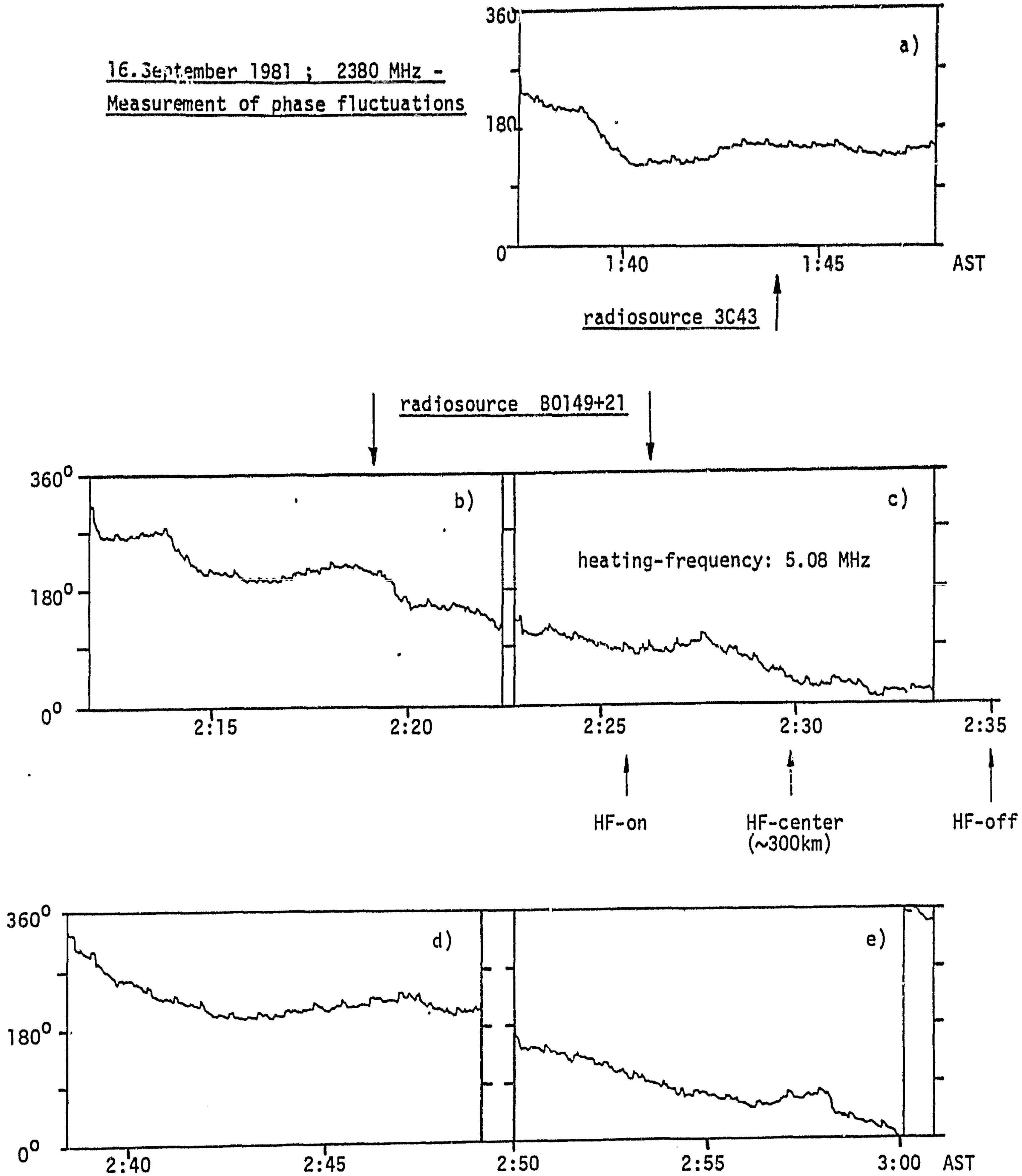

16. September 1981 ; 2380 MHz -
Measurement of phase fluctuations
a)
360
180
0
1:40
1:45
AST
radiosource 3C43
radiosource B0149+21
b)
c)
heating-frequency: 5.08 MHz
360°
180°
0°
2:15
2:20
2:25
2:30
2:35
HF-on
HF-center
(~300km)
HF-off
d)
e)
2:40
2:45
2:50
2:55
3:00
AST

Figure 4.1.

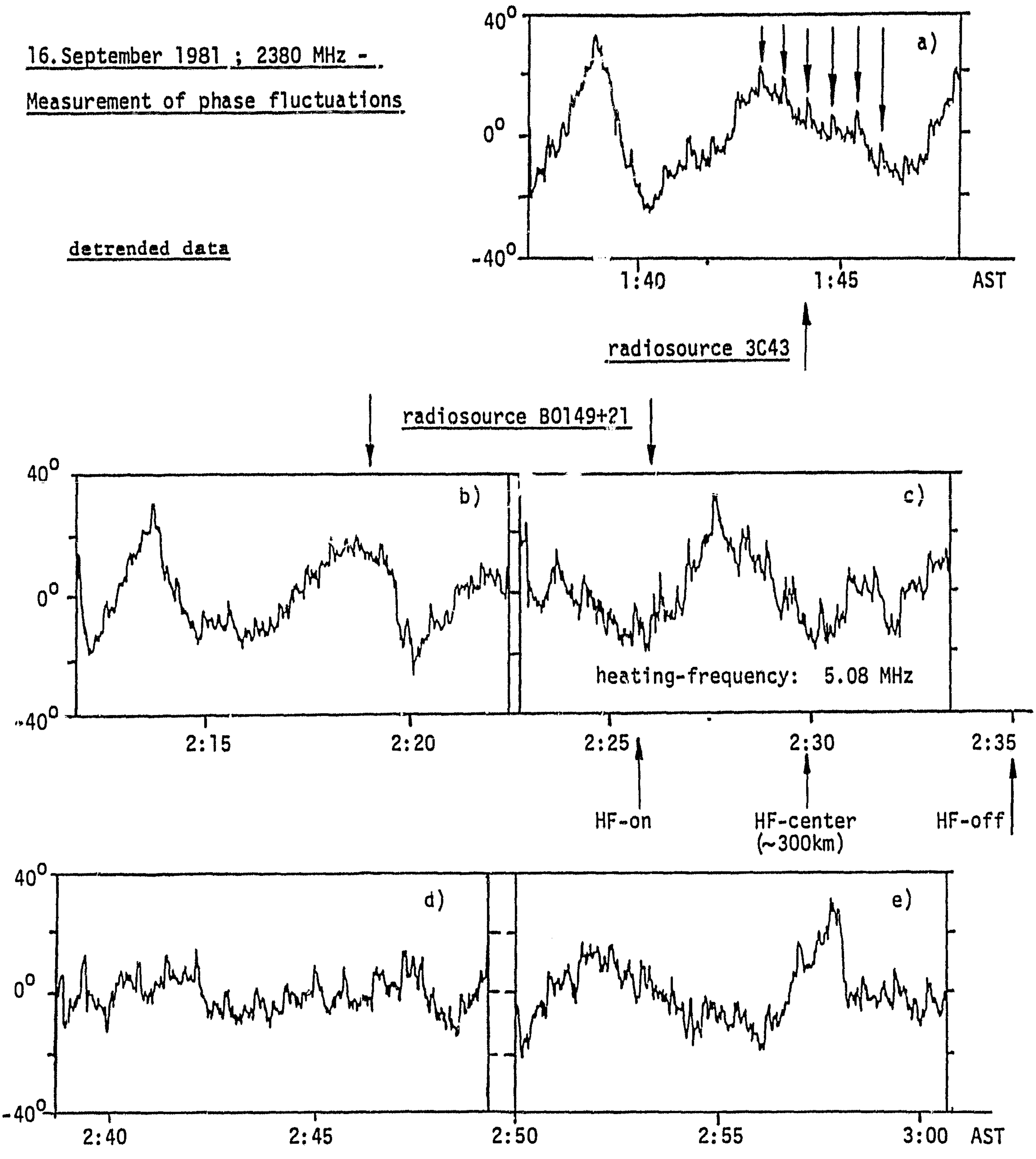

16. September 1981 ; 2380 MHz -
Measurement of phase fluctuations
detrended data
a)
40°
0°
-40°
1:40
1:45
AST
radiosource 3C43
radiosource B0149+21
b)
c)
heating-frequency: 5.08 MHz
2:15
2:20
2:25
2:30
2:35
HF-on
HF-center
(~300km)
HF-off
d)
e)
2:40
2:45
2:50
2:55
3:00
AST

Figure 4.2.

Strong phase fluctuations exceeding 80° over time intervals of ~ 2 minutes were recorded at ~ 3:32 AST. The electron density irregularities producing these phase fluctuations are assumed natural since the HF-transmitters were turned off about one hour earlier.

The HF-power was turned on at 3:46 AST with 4 transmitters feeding 100 kW each into the full antenna array. Assuming an interaction height of 300 km this corresponds to a power density of ~ 56 $\mu W/m^2$ at an HF-frequency of 5.08 MHz. At 3:51:10 AST the HF-power was increased to 150 kW for each transmitter thereby increasing the HF-power density to ~ 84 $\mu W/m^2$. The SPS-equivalent (2450 MHz) power density is 1.9 mW/cm^2. No obvious changes in the pattern of phase fluctuations as a result of HF-modification are observed (see Figs. 5.1.c & d and Figs. 5.2.c & d). Rapid fluctuations in phase of 2°/second are observed during natural (Fig. 5.2.b) and HF-modified conditions.

On the 17 September 1981 starting at 2:11:20 AST radio source B0149+21 was observed until 2:57:49 AST. The raw phase fluctuations are shown in Fig. 6.1 and the detrended phase fluctuations are shown in Fig. 6.2. The strong phase fluctuations due to natural irregularities observed on the previous day are weaker (less than 10°) during this observation and have periods of ~ 4 minutes. The HF-power was turned on at 2:17 AST transmitting at a frequency of 7.3 MHz with 4 transmitters feeding 100 kW each into the full antenna-array. This corresponds to an HF-power density of ~44 $\mu W/m^2$. The HF-wave polarization corresponded to O-mode heating. The SPS-equivalent (2450 MHz) power density is 0.5 mW/cm^2. At 2:26:47 AST about 1 minute after the line of sight to the radio source passed the center of the HF-beam the HF-polarization was changed to X-mode heating, and finally at 2:32:09 the HF-power was turned off. As seen from Figs. 6.1 and 6.2 no clear effects of the HF-modification on the phase fluctuations is observed.

16.September 1981 ; 2380 MHz - Measurement of phase fluctuations.

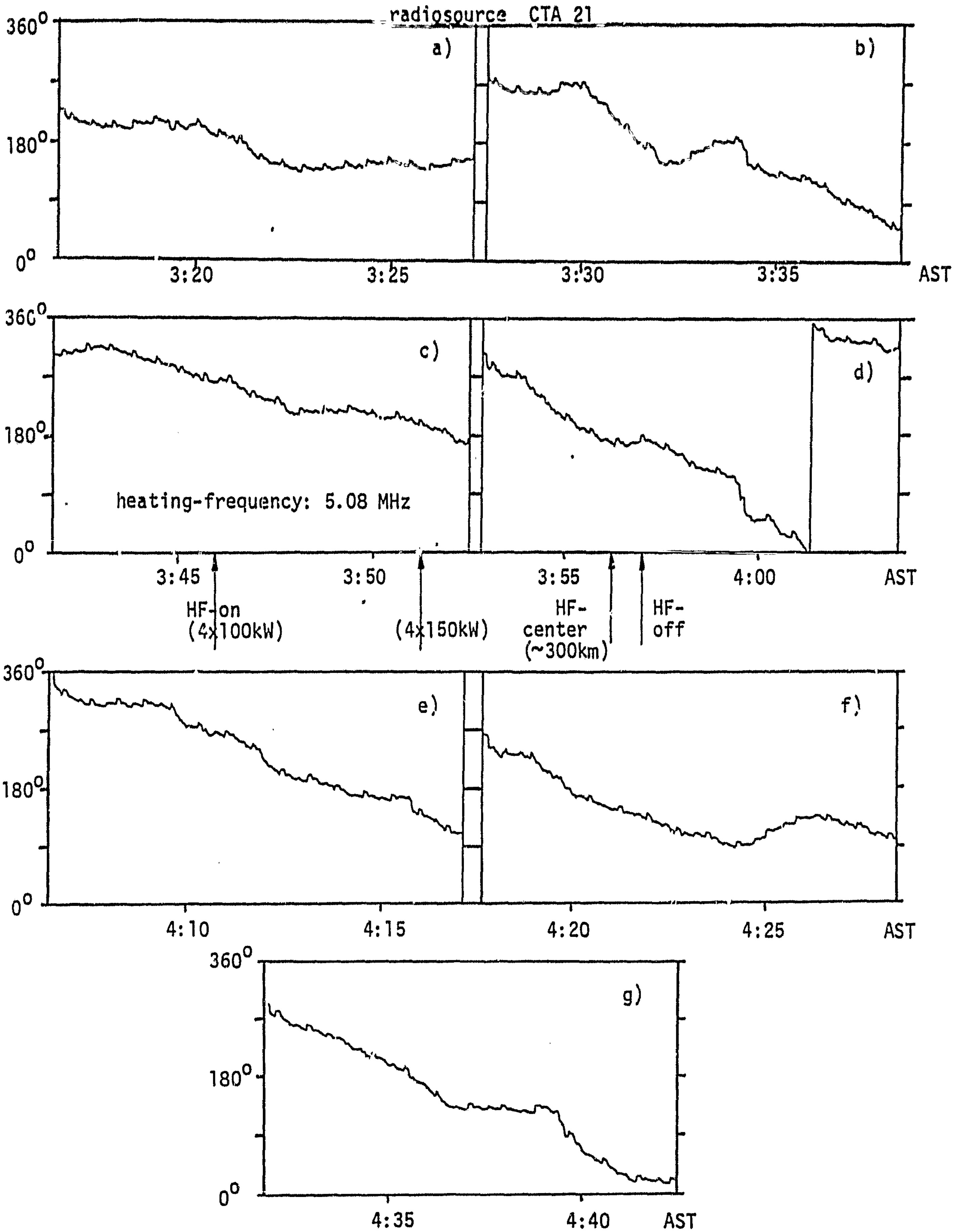
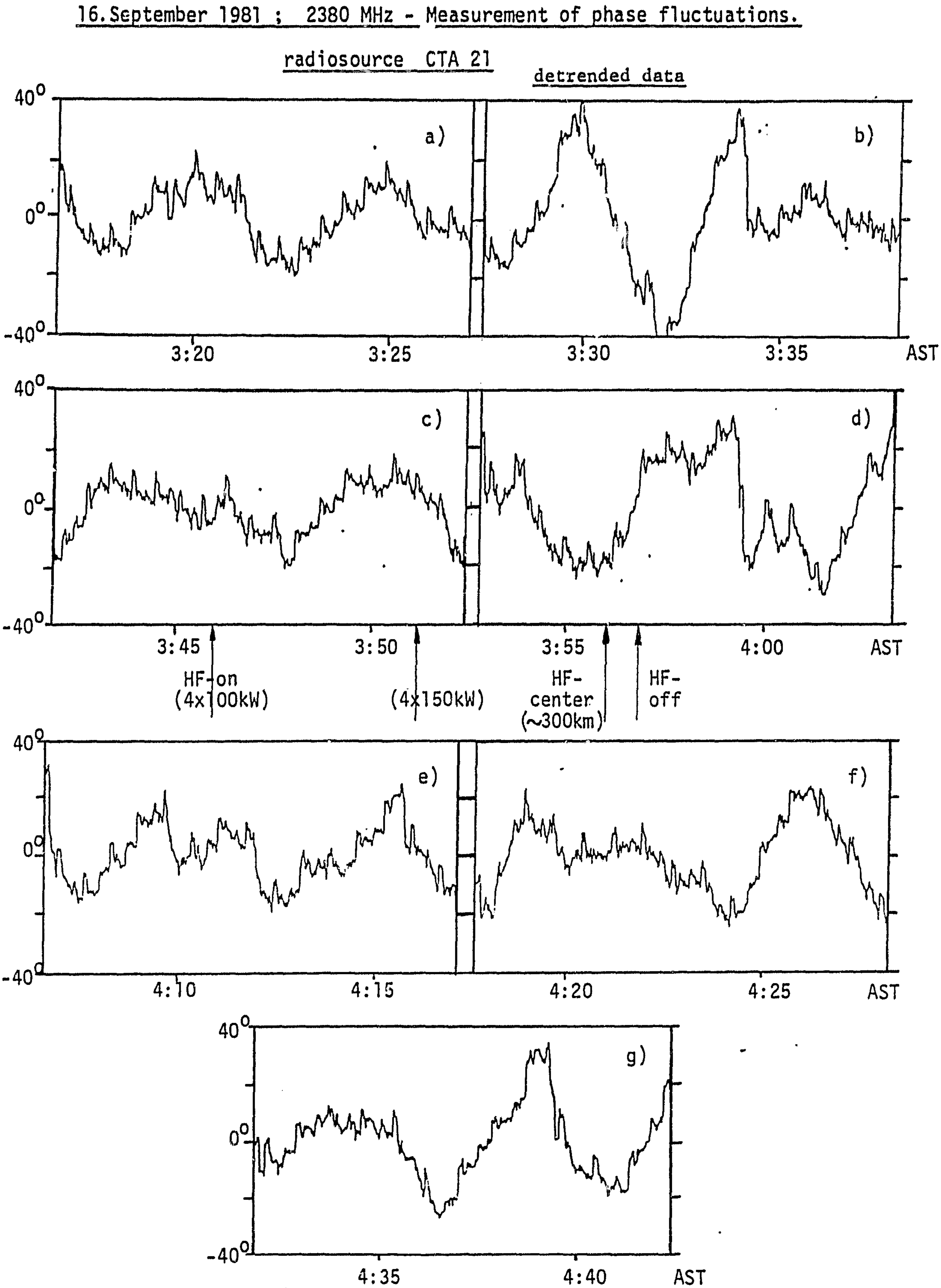


Figure 5.1.



16. September 1981 ; 2380 MHz - Measurement of phase fluctuations.
radiosource CTA 21
detrended data
a)
b)
c)
d)
e)
f)
g)
40°
0°
-40°
3:20
3:25
3:30
3:35
3:45
3:50
3:55
4:00
4:10
4:15
4:20
4:25
4:35
4:40
AST
HF-on (4x100kW)
(4x150kW)
HF-center (~300km)
HF-off

Figure 5.2.

17 September 1981 ; 2380 MHz - Measurements of phase fluctuations.

radiosource B0149+21

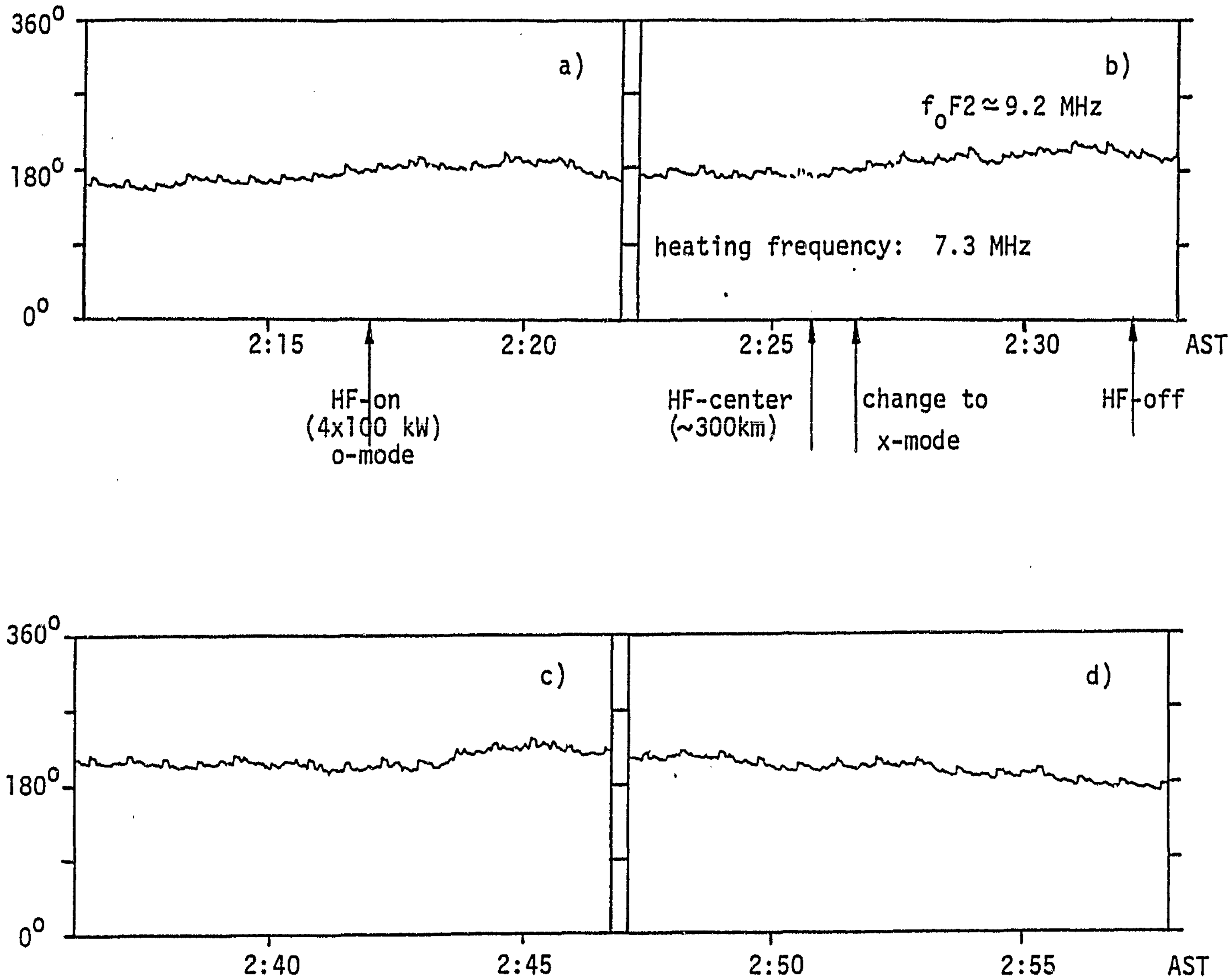


Figure 6.1.

17 September 1981 ; 2380 MHz - Measurements of phase fluctuations.

detrended data

radiosource B0149+21

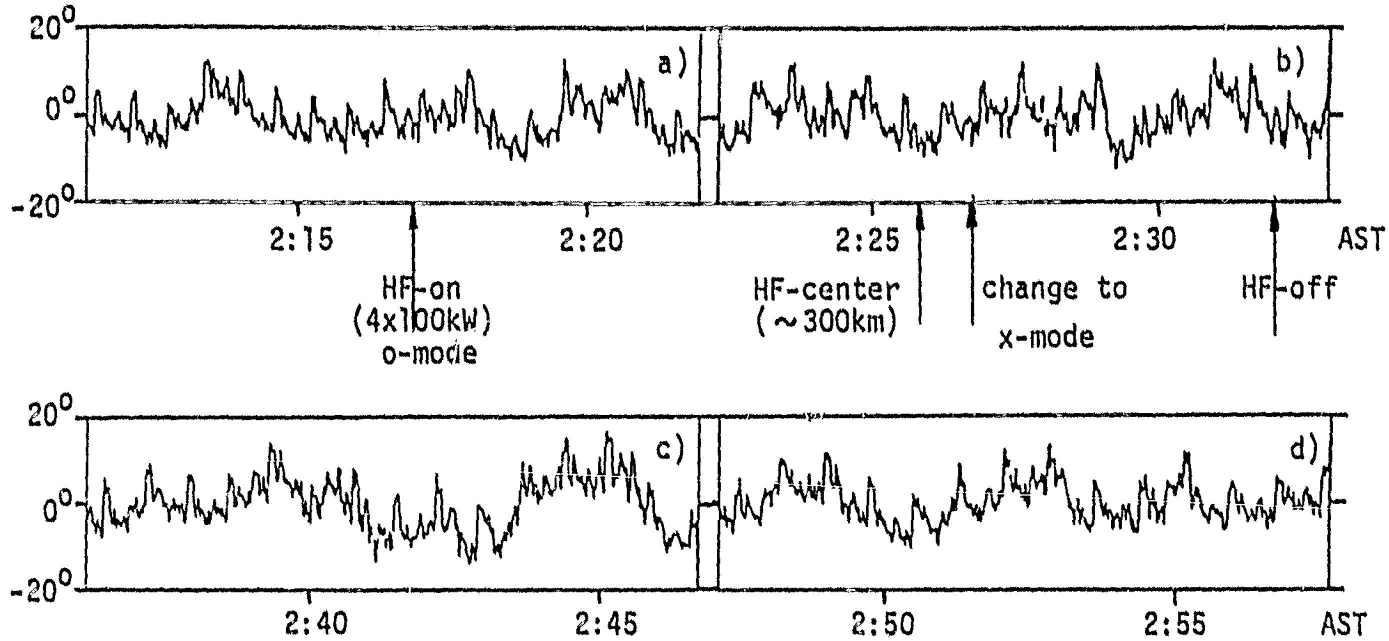


Figure 6.2.

During the period from 3:10:40 AST until 4:46:19 AST on the 17 September 1981 the radio source CTA21 was observed. The raw phase fluctuations are shown in Fig. 7.1 and the detrended phase fluctuations are shown in Fig. 7.2. Slow (~ 6 min) phase fluctuation of about 6° are observed initially (Fig. 7.2.b) and are probably due to natural electron density irregularities, since the HF-power had been off for about 50 minutes. At 3:40 AST the HF-power is turned on with 2 transmitters feeding 150 kW and the other 2 transmitters feeding 100 kW into the full antenna. At 3:42 AST all 4 transmitters are feeding 150 kW into the full antenna at an HF-frequency of 7.3 MHz. This corresponds to an HF-power density of ~ 66 $\mu W/m^2$ at a height of 300 km. The SPS-equivalent (2450 MHz) power density is 0.7 mW/cm^2. The HF-wave polarization corresponds to X-mode heating. At 3:49:40 the polarization is changed to O-mode. At 3:54:20 the HF-power was turned off. During this heating period the critical frequency for the O-mode was very near the HF-frequency and slowly decreasing. At 3:38 AST $f_o f2$ was 7.4 MHz and at 3:47 AST $f_o f2$ was 7.3 MHz. Finally at 4:15 AST $f_o f2$ was 7.0 MHz.

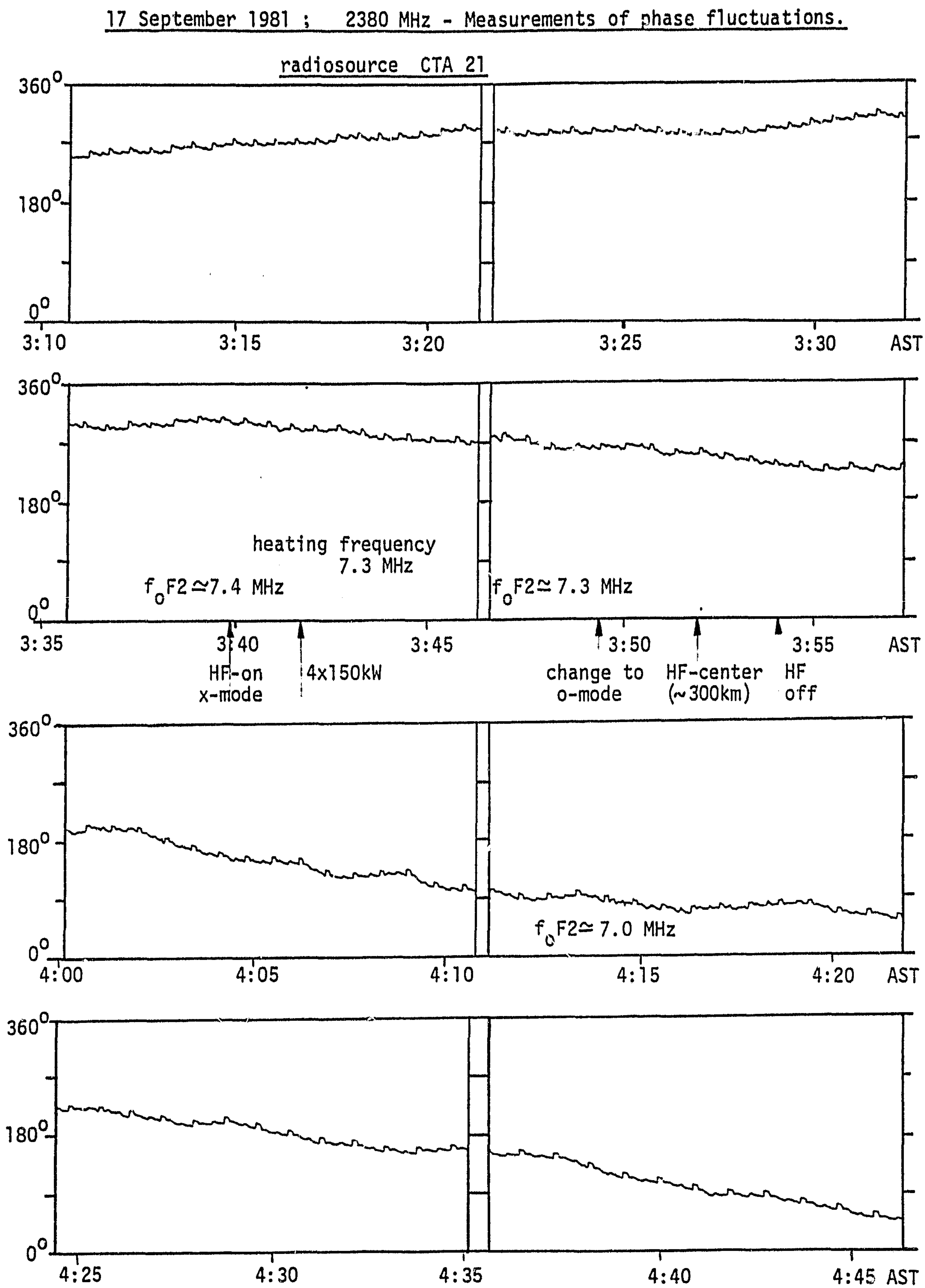

17 September 1981 ; 2380 MHz - Measurements of phase fluctuations.
radiosource CTA 21
360°
180°
0°
3:10
3:15
3:20
3:25
3:30
AST
heating frequency 7.3 MHz
$f_oF2 \simeq 7.4$ MHz
$f_oF2 \simeq 7.3$ MHz
3:35
3:40
3:45
3:50
3:55
HF-on x-mode
4x150kW
change to o-mode
HF-center (~300km)
HF off
$f_oF2 \simeq 7.0$ MHz
4:00
4:05
4:10
4:15
4:20
4:25
4:30
4:35
4:40
4:45

Figure 7.1.

17 September 1981 ; 2380 MHz - Measurements of phase fluctuations.

radiosource CTA 21

detrended data

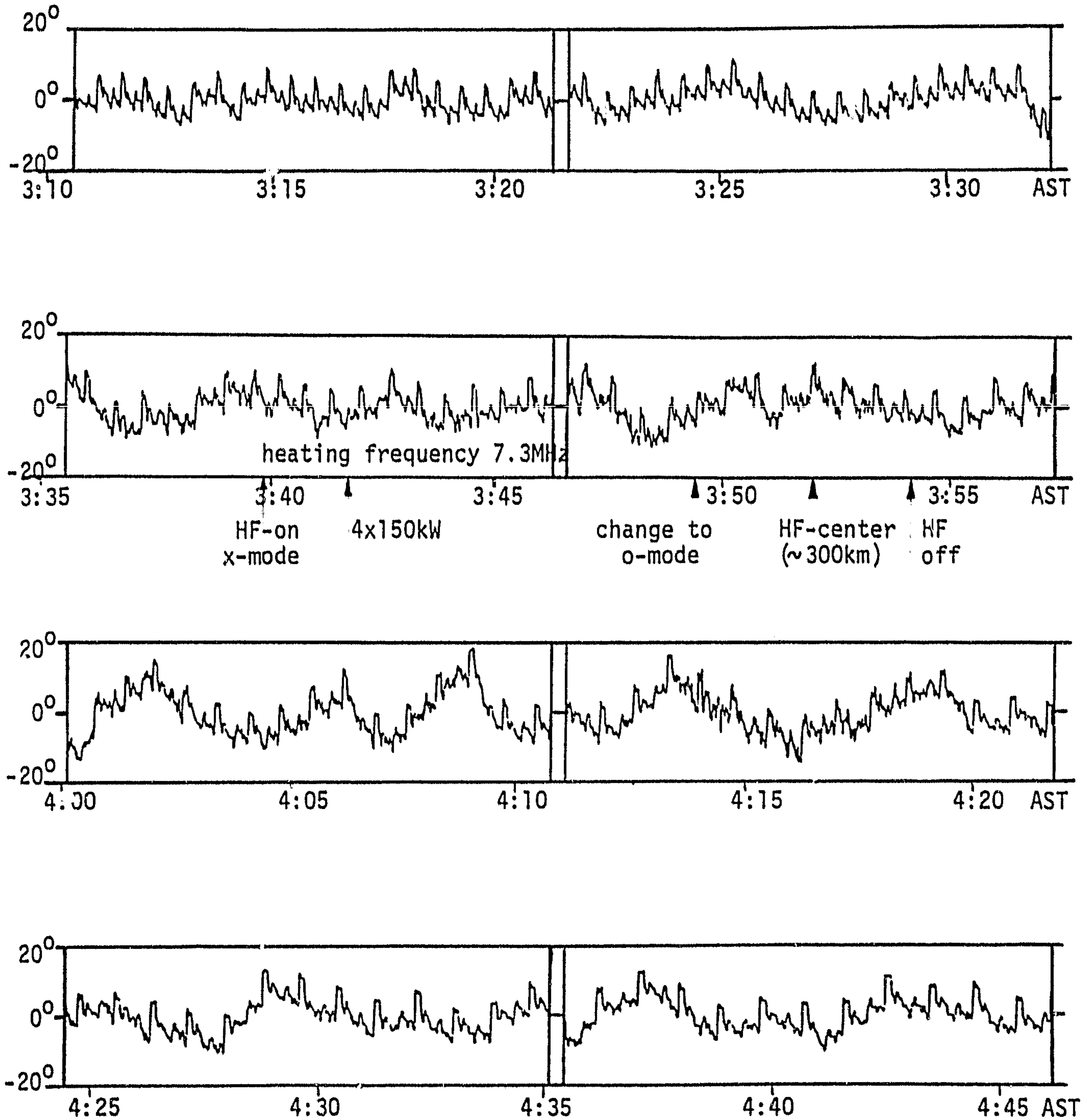


Figure 7.2

b) <u>430 MHz Observations</u>

Starting at 1:06:38 AST on the 12 October 1981 radio source 3C47 was observed until 1:28:37 AST. The phase fluctuations are shown in Fig. 8.1 and the intensity fluctuations as observed with the 300 m-dish are shown in Fig. 8.2. Phase fluctuations exceeding 180° and intensity fluctuations as large as 8% (excursion from the mean) are measured. At ~ 1:11 AST the phase changes at a rate of about 4°/second. The line of sight to the radio source was about 5 to 10° to the west of the HF-modified volume during the above mentioned observation period. Two HF-transmitters were turned on for a time period not well known, transmitting 100 kW each. The HF-transmitters were turned off at the latest at 1:15 AST to let the ionosphere relax to its natural condition for the next observation.

Starting at 2:05:08 AST on the 12 October 1981 radio source CTA21 was observed until 2:26:47 AST. The detrended phase fluctuations at 430 MHz are shown in Fig. 9.1 and the intensity fluctuations at 430 MHz are shown in Fig. 9.2. The HF-power was turned on at 2:07:15 AST with 2 transmitters feeding 100 kW each into the full antenna. This corresponds to an HF-power density of 28 $\mu W/m^2$ for an HF-frequency of 5.1 MHz. The HF-wave polarization corresponded to X-mode heating. The SPS-equivalent (f = 2450 MHz) power density is 0.6 mW/cm^2. At 2:13:30 AST about 1 minute before the line of sight to CTA21 was passing to the south of the center of the HF-beam (as illustrated in Fig. 2) the HF-power was increased. The 2 transmitters were now feeding 150 kW each into the full antenna. This corresponds to an HF-power density of 42 $\mu W/m^2$. The SPS-equivalent (f = 2450 MHz) power density is 1.0 mW/cm^2. At 2:19:00 AST the HF-wave polarization was changed to O-mode while the line of sight to CTA21 was still within the HF-halfpower beamwidth. At 2:10 AST the intensity measured with the 300-m dish starts to show increasing fluctua-

12 October 1981 ;   430 MHz - Measurements of phase fluctuations

radiosource 3C 47

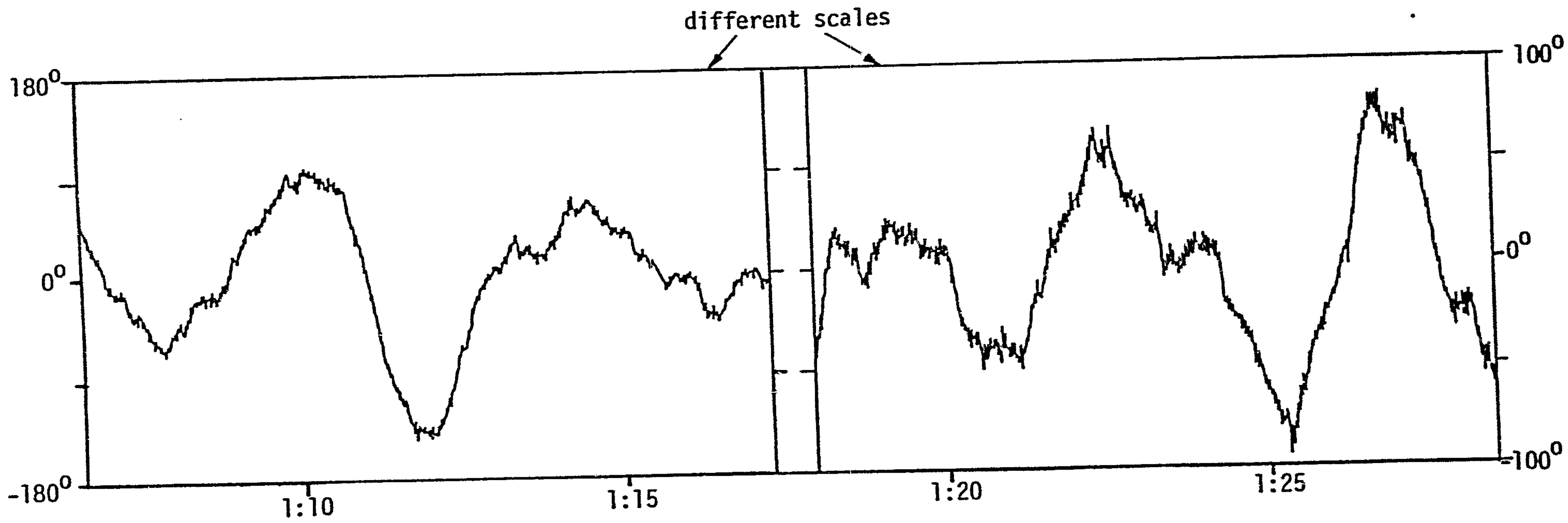


Figure 8.1.

12 October 1981 ; 430 MHz - Measurements of intensity-fluctuations

radiosource 3C 47

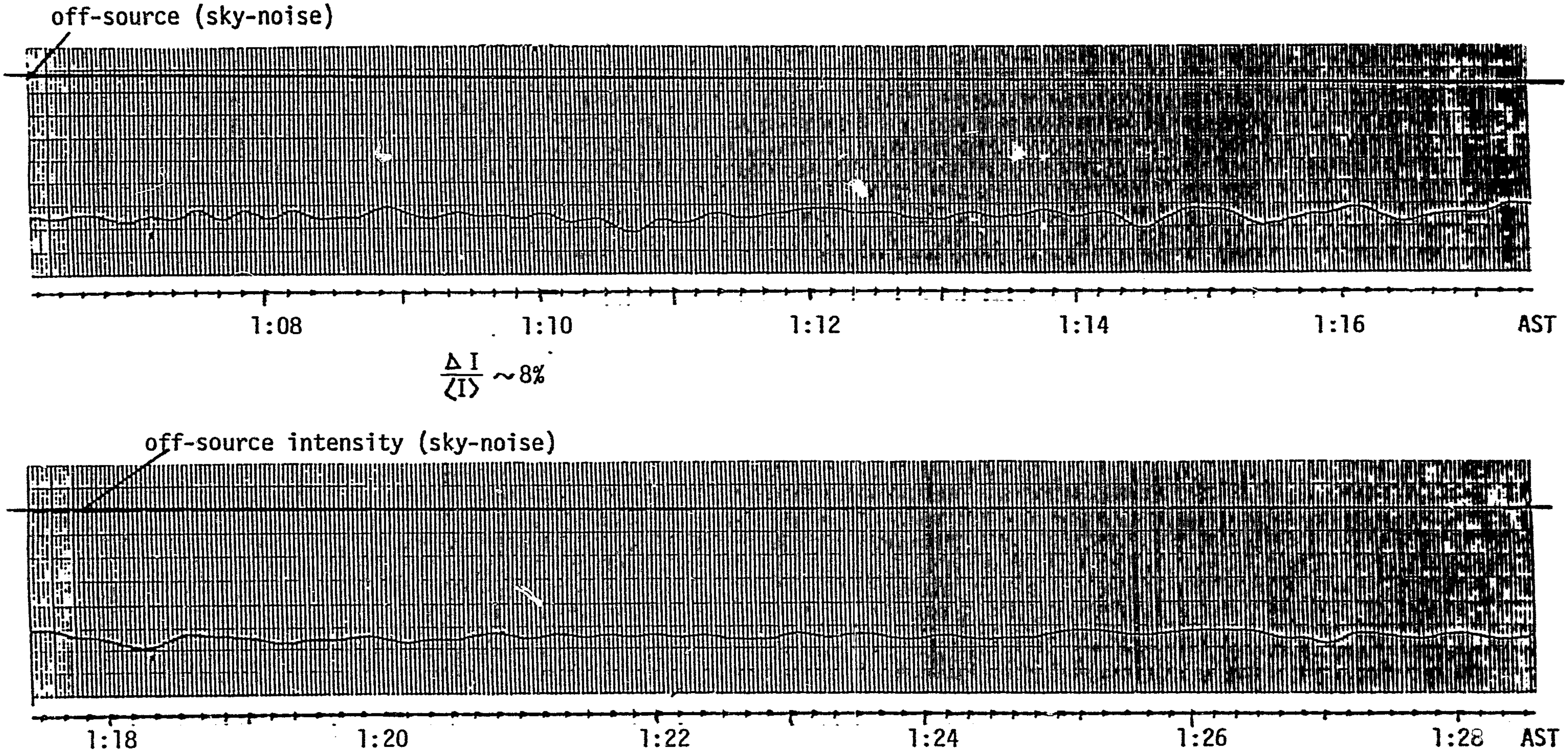


Figure 8.2.

12 October 1981 ;   430 MHz - Measurements of phase fluctuations

radiosource   CTA 21

detrended data

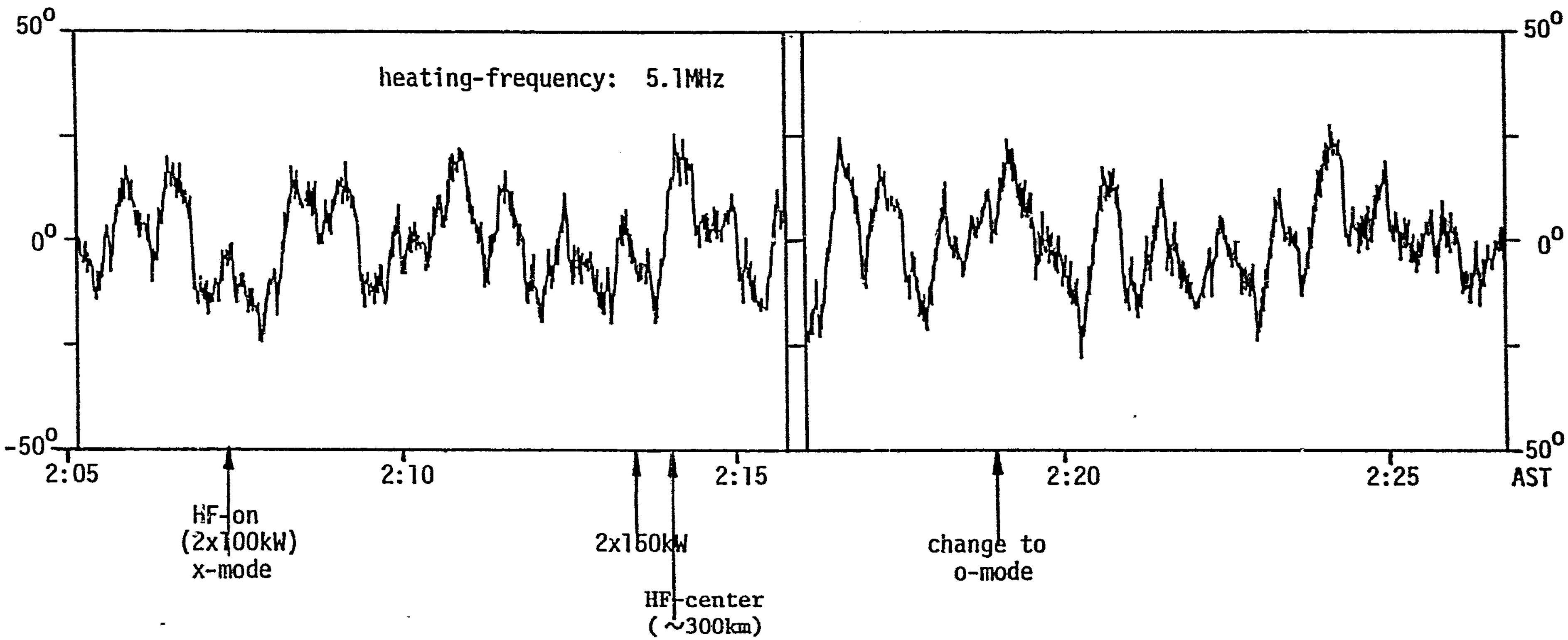


Figure 9.1.

12 October 1981 ; 430 MHz - Measurements of intensity-fluctuations

radiosource CTA 21

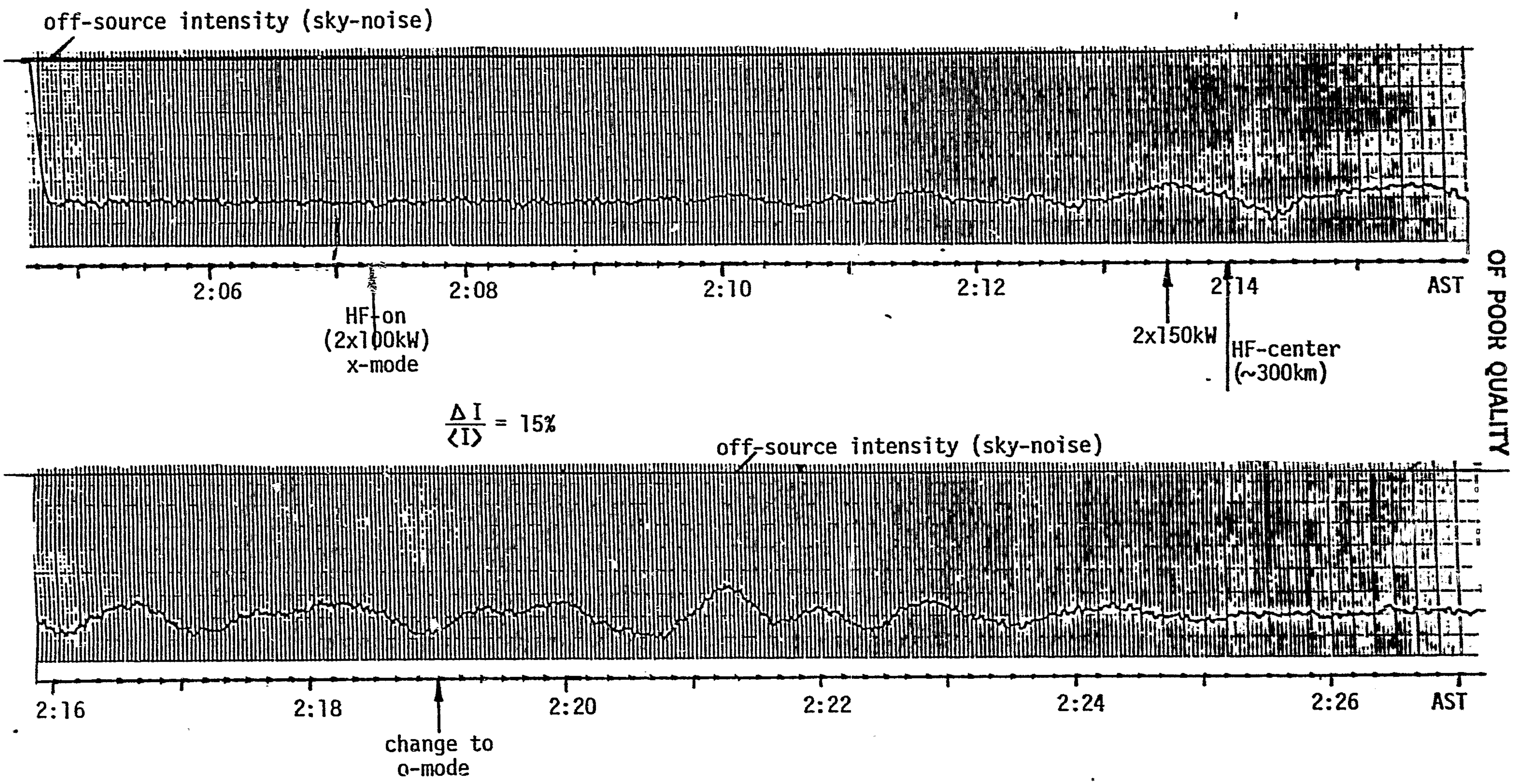


Figure 9.2.

tions about 3 minutes after the HF-power was turned on (see Fig. 9.2). This observation shows that also X-mode heating is capable of producing ionospheric irregularities. The intensity fluctuations are as large as 12-15% (excursion from the mean). This corresponds to phase fluctuations of 8-10° in phase at the thin phase screen after Fresnel- and Antenna-filtering are taken into account [Frey, 1982]. These same filtering effects also make the intensity fluctuations most sensitive to phase irregularities which have a wavelength of ~ 700 m at the thin phase screen. The phase-fluctuations illustrated in Fig. 9.1 show no fluctuations which can be ascribed to HF-heating. The fluctuations observed are most likely instrumental (oscillations in the feed support structure) and make it difficult to observe phase fluctuations due to ionospheric irregularities unless they exceed 25° in phase.

Starting at 0:07:48 AST on the 13 October 1981 radio source 3C47 was observed at 430 MHz until 0:51:47 AST. The HF-power was turned on at ~ 0:16 AST with two transmitters feeding 100 kW each into the full antenna. This corresponds to an HF-power density of 22 $\mu W/m^2$ at a transmitted frequency of 7.3 MHz. The SPS-equivalent (f = 2450 MHz) power density is 0.25 mW/cm^2. The polarization of the transmitted waves corresponded to X-mode. At 0:39 AST the HF-power was turned off. The source intensity measured with the 300 m-dish is shown in Figs. 10.2.a&b. The first intensity fluctuations start at 0:20 AST about 4 minutes after the HF-power was turned on. The intensity fluctuations reach about 7-8% (excursion from the mean). This corresponds to phase fluctuations of ~ 5° in phase at the thin phase screen after Fresnel- and Antenna-filtering are taken into account [Frey, 1982]. These same filtering effects also make the intensity fluctuations most sensitive to phase irregularities having a wavelength of ~ 700 m at the thin phase screen. Above observation is another example that X-mode heating can produce ionospheric irregularities.

The phase-fluctuations illustrated in Figs. 10.1.a&b show some evidence of phase irregularities as large as 30 to 50° in phase around the times 0:23, 0:28, 0:30, and 0:45 AST. These fluctuations could be due to HF-heating.

13 October 1981 ;   430 MHz - Measurements of phase-fluctuations

radiosource 3C 47

detrended data

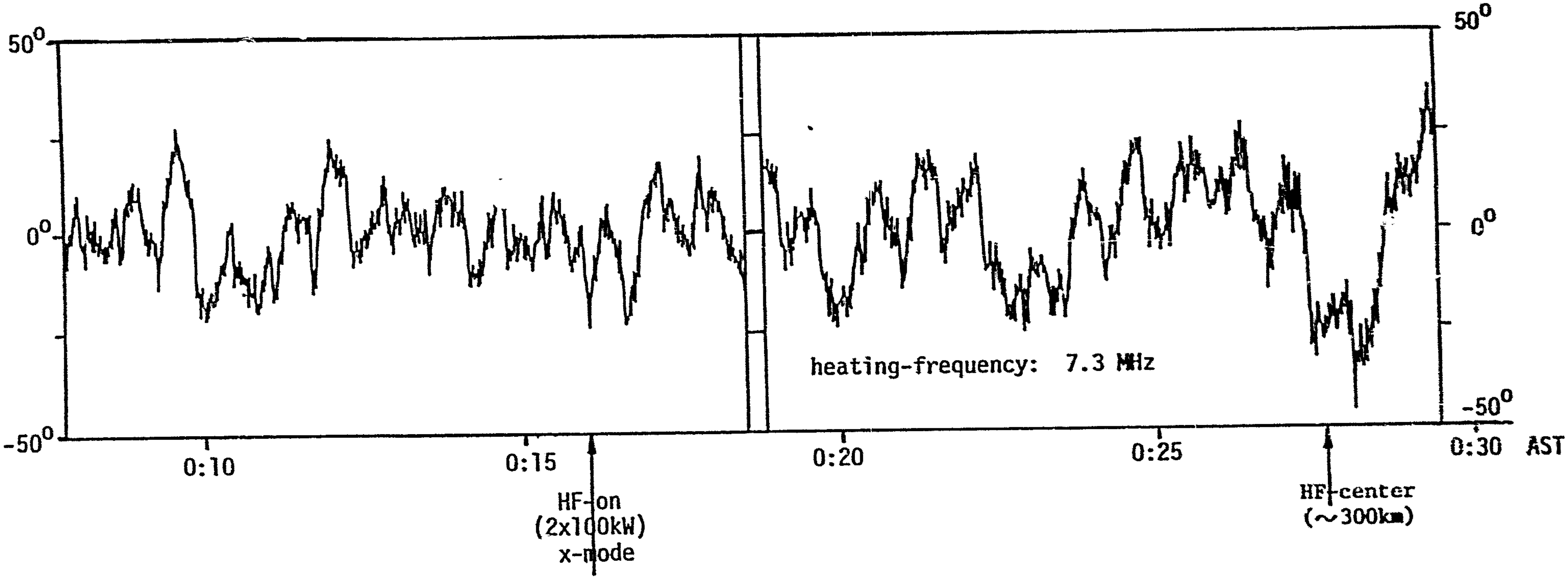


Figure 10.1.a.

13 October 1981 ; 430 MHz - Measurements of phase-fluctuations

radiosource 3C 47

detrended data

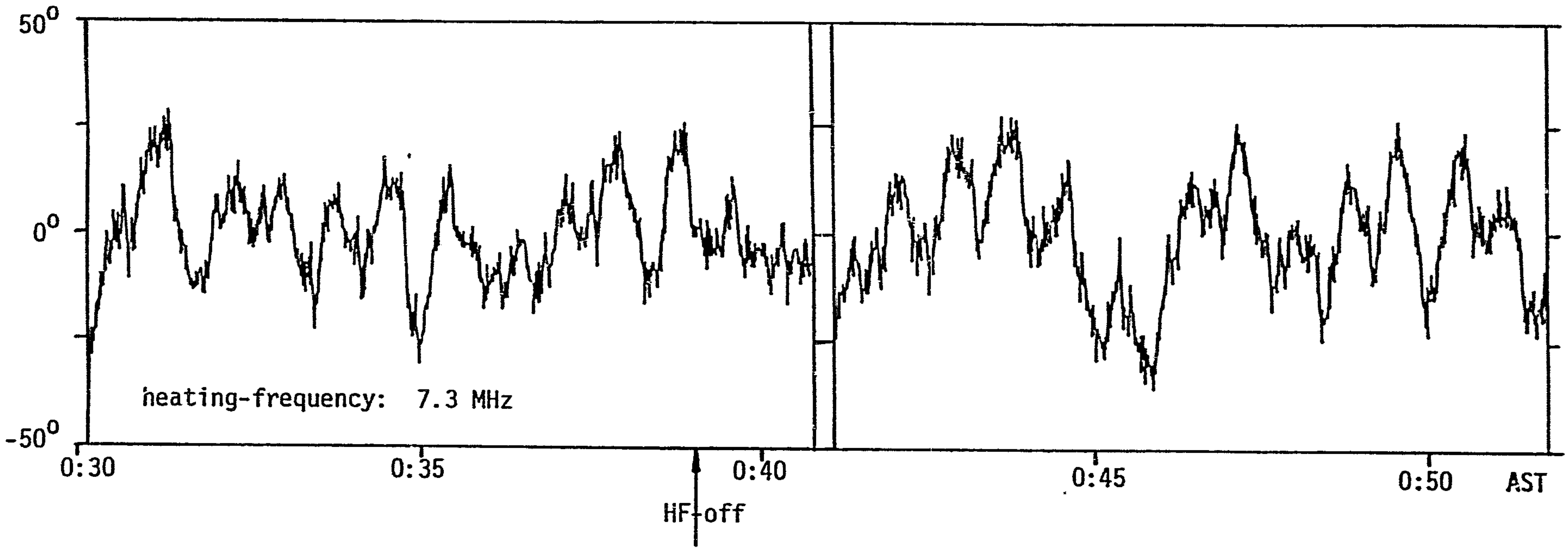


Figure 10.1.b.

13 October 1981 ; 430 MHz - Measurements of intensity-fluctuations

radiosource 3C 47

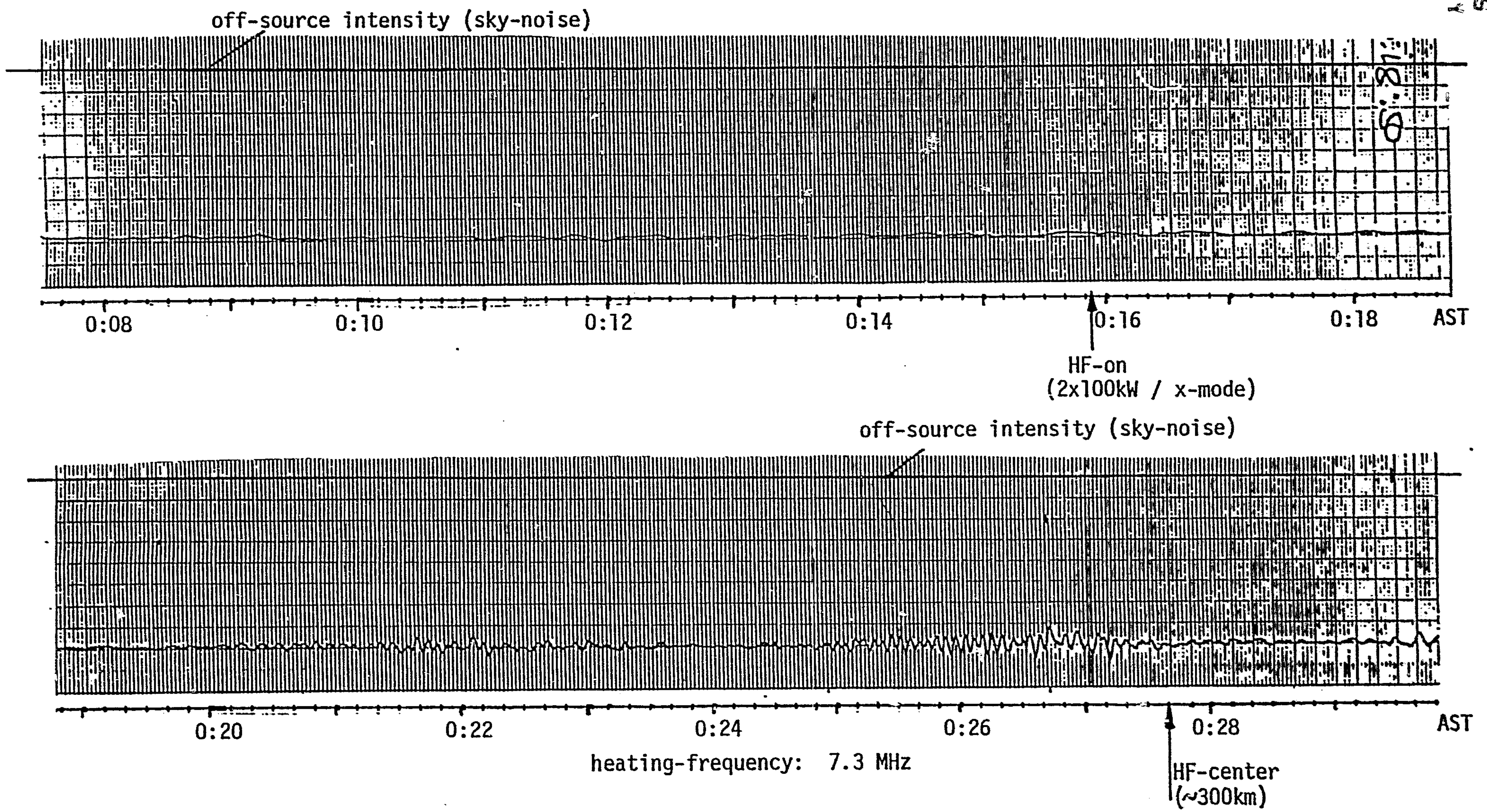


Figure 10.2.a.

13 October 1981 ; 430 MHz - Measurements of intensity-fluctuations

radiosource 3C 47

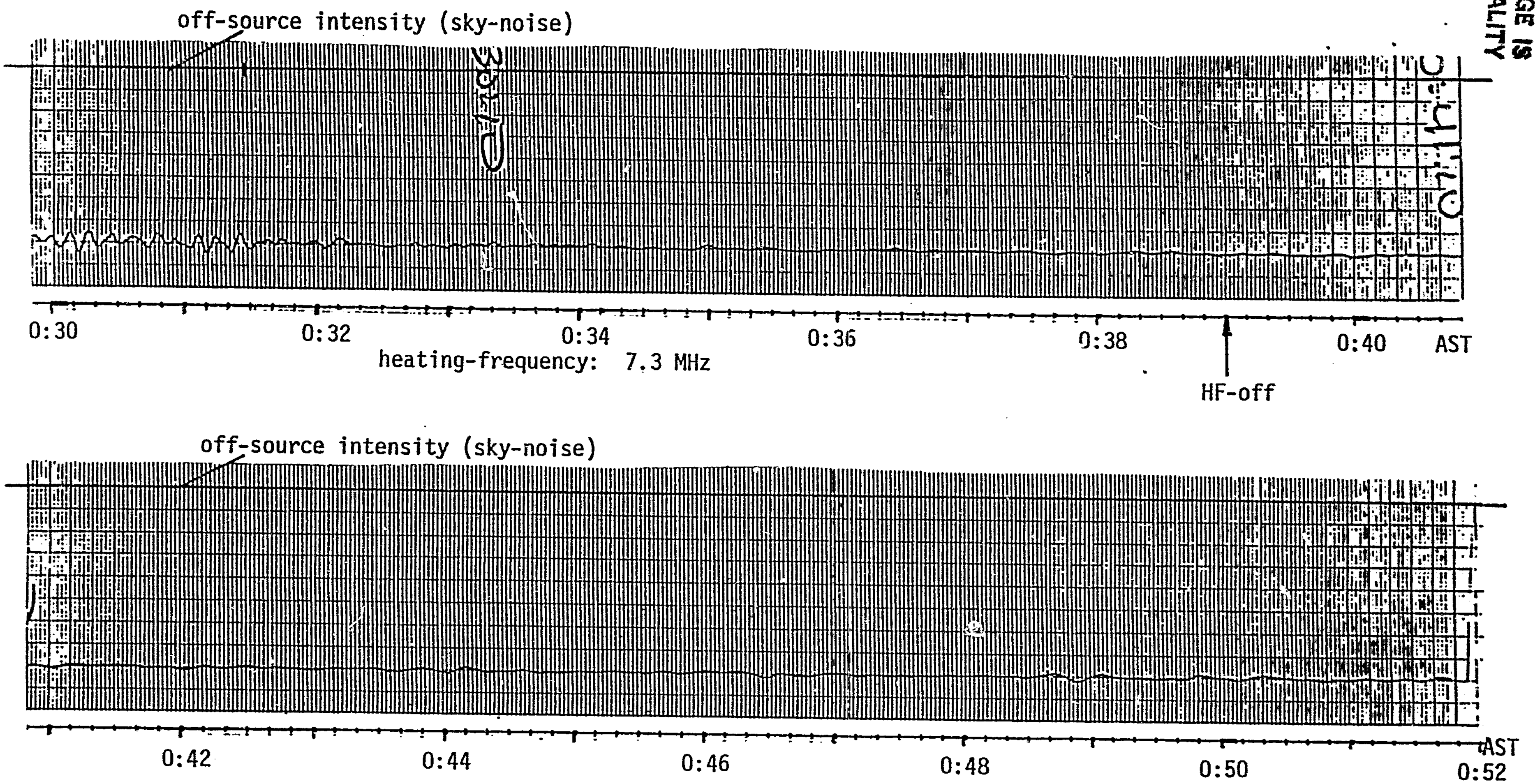


Figure 10.2.b.

4. Interpretation

From the measurements reported in section 3 there is no clear evidence that the phase fluctuations which were observed are the direct result of HF-modification of the ionosphere. The phase fluctuations observed have generally the same appearance before and after the HF-power is turned on. Phase fluctuations as large as 60-90° at an observing frequency of 2380 MHz and having a period of about 5 minutes were observed on one day (16 Sept. 1981; Figs. 4.2 and 5.2) and are probably due to natural ionospheric irregularities. Phase fluctuations as large as 180-240° at an observing frequency of 430 MHz and having a period of ~ 5 minutes are probably due to natural irregularities and were observed on another day (12 Oct. 1981; Fig. 8.1). Measurements performed at Socorro, New Mexico using an observing frequency of 5 GHz and communicated by [A. Marouf and G. D. Arndt, 1980] show quite regularly strong phase fluctuations due to the natural ionosphere (assuming phase fluctuations due to the troposphere are less than ~ 10°). Besides phase fluctuations exceeding 180° and having periods on the order of one hour smaller phase fluctuations of ~ 40° and having a period of about 5 minutes are very common in those observations and are consistent with Figs. 4.2 and 5.2.

In view of these strong phase fluctuations due to natural irregularities it seems clear that days with a quiet ionosphere are needed to establish an upper limit on the phase perturbations which can be produced by HF-modification and observed by phase-observations. The 17 September 1981 was a relatively quiet day and phase fluctuations at 2380 MHz are less than 10 to 20° before the HF-power is turned on. There appears to be a slight increase in phase fluctuations by 5-10° after the HF-power is turned on (Figs. 6.2 and 7.2). It is not clear from just two observations whether the increase was naturally caused or whether the HF-waves enhanced the natural irregularities

already present. We therefore assume that if there are phase fluctuations at 2380 MHz which are due to HF-modification of the ionosphere, they are less than 5-10°.

For practical reasons (insufficient pointing accuracy) measurements at 2380 MHz cannot be used to obtain intensity scintillations. At 430 MHz intensity scintillations as large as 40% (excursion from mean) have been observed as a result of HF-modification of the ionosphere [Frey, 1982]. For the 430 MHz observations reported here intensity scintillations have been observed (Figs. 8.2, 9.2, 10.2.a&b) as a by-product to the phase-scintillations (Figs. 8.1, 9.1, 10.1.a&b). As was shown [Frey, 1982] filtering effects at an observing frequency of 430 MHz using the Arecibo 300 m-dish make the intensity fluctuations most sensitive to electron density irregularities having a horizontal wavelength of ~ 700 m. This accounts for the quasi-periodic intensity fluctuations observed most of the time when the heater was on. The presence of these irregularities indicates that HF-power is indeed reaching the ionosphere and producing electron density irregularities having a horizontal wavelength of ~ 700 m. The temporal intensity fluctuations due to these 700 m irregularities allow us to estimate the scanning velocity of these irregularities which in turn can be used to estimate the horizontal wavelength of the irregularities causing the phase scintillations. The scanning velocity is the velocity at which the line of sight to the radio source scans the ionospheric electron density irregularities. From Fig. 8.2 we have for the quasi-periodic intensity fluctuations near 1:08 AST a period of ~ 20 sec. For an irregularity with a wavelength of ~ 700 m we obtain a scanning velocity of ~ 35 m/sec. In Fig. 8.1 we see phase fluctuations as large as 180° having periods of about 5 minutes. With a scanning velocity of ~ 35 m/sec we conclude that the electron density irregularities producing these phase

fluctuations have a horizontal wavelength of ~ 10 km. It is usually assumed that the 2-dimensional spectrum of natural ionospheric electron density irregularities follows a power law given by K^{-p} where p is the spectral index usually assumed to be between 2 and 3 and $K = 2\pi/\lambda_{irr}$ is the wavevector of the irregularities. Assuming the 10 km irregularities are due to the natural ionosphere one can extrapolate that the phase fluctuations due to ~ 700 m irregularities are less than 1° for the natural ionosphere. The intensity fluctuations of 8% (excursion from the mean) seen in Fig. 8.2 correspond to phase fluctuations of ~ 5° with due consideration of the filtering effects [Frey, 1982]. To establish an upper limit on the phase fluctuations at 430 MHz which are the result of HF-modification we choose the two observations (Figs. 9.1, 10.1a & 10.1.b) which were performed on days with a low level of natural irregularities. Apart from the quasiperiodic fluctuations which have a period of ~ 50 sec and are always present (independent of the HF-power) there are some phase fluctuations between 0:28-0:31 AST and near 0:45 AST (see Figs. 10.1.a & b) which are as large as 30° to 80° and which could be due to HF-modification. We therefore conclude that if HF-modification at the present power levels (refer to Table 1) does produce phase fluctuations they are less than about 80°. It should be noted that most of the heating was in x-mode and any irregularities produced would be the result of some ohmic dissipation process. These observations are therefore particularly interesting in context with the SPS microwave beam. The intensity fluctuations observed on the 12 October 1981 (see Fig. 9.2) show a clear response to HF-power turn-on within about 3 minutes. The intensity fluctuations due to HF-modification became as strong as 15% (excursion from the mean). This corresponds to phase fluctuations of ~ 10° if the filtering effects important to intensity fluctuations [Frey, 1982] are taken into consideration. Such a small change in phase is

not easy to detect in the background of the larger persistent phase fluctuations of Fig. 9.1. Similar arguments can be used for the observations performed on the 13 October 1981 (Figs. 10.1 & 10.2, a&b).

5. Conclusions relevant to the SPS

Phase fluctuations due to natural ionospheric irregularities on perturbed days are much stronger than the irregularities which result from HF-modification for the HF-power density levels presently achieved. The maximum HF power densities used in this experiment were in the range of 20-80 $\mu W/m^2$ which is equivalent to a maximum power density for the SPS microwave (2450 MHz) in the range of 0.3 to 1.9 mW/cm^2. The ionospheric irregularities which may be produced by the HF-power are comparable with natural irregularities on quiet days. It is therefore difficult to claim with certainty whether the phase fluctuations observed are caused by natural or HF-produced ionospheric irregularities.

If the increase in phase fluctuations of 5-10° at 2380 MHz (Figs. 6.2 & 7.2) and 30-80° at 430 MHz (Figs. 10.1 a & b) are indeed the result of HF modification, then we could set an upper limit of ~ 10° for the phase perturbations on the SPS uplink microwave beam (2450 MHz). These observations which indicate some possible effects of HF-modification were performed with SPS-equivalent maximum power densities of less than 0.7 mW/cm^2. This is substantially less than the expected power density of 20 mW/cm^2 for the SPS downlink microwave beam. It is also interesting to note that all observation periods which show some indication of HF induced effects correspond to periods during which the HF-frequency was 7.3 MHz rather than 5.08 MHz (refer to Table 1). Phase fluctuations less than 10° at 2450 MHz are no serious problem to the uplink pilot beam.

Further experiments using higher HF-power densities and higher HF-frequencies will be needed to shed more light on the effects to be expected for the real SPS-arrangement.

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